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A RAY-DISPLACEMENT REFRACTOMETER FOR ACCURATE WORK

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ABSTRACT. The paper describes a very convenient and accurate type of refractometer, which can be built up in any Physical laboratory without much trouble. The probable error of the mean value of μ determined by this apparatus is found to be $\pm$ ·0002 and possesses a high degree of reproducibility.

It is specially suited for the determination of μ of thin transparent plates obtainable in small sizes, but can also be used for liquids.

§ 1. INTRODUCTION AND THEORY.

In a paper read before the Indian Science Congress at Patna in 1933, and published elsewhere,[1] it was shown that by using the equations

$$d = \frac{t \sin (i-r)}{\cos r} \qquad \ldots (1)$$

and

$$\mu = \frac{\sin i}{\sin r}, \qquad \ldots (2)$$

the refractive index of a plate of thickness t on which a ray of light is incident at an angle i, producing a lateral shift of magnitude d, can be calculated with the help of the following equation obtained by eliminating r between the above two equations, namely

$$\mu = \frac{\sin i}{t \sin i - d} \sqrt{d^2 + t^2 - 2d.\, t.\, \sin i} \qquad \ldots (3)$$

Figure 1 shows the incident and the displaced path of a ray.

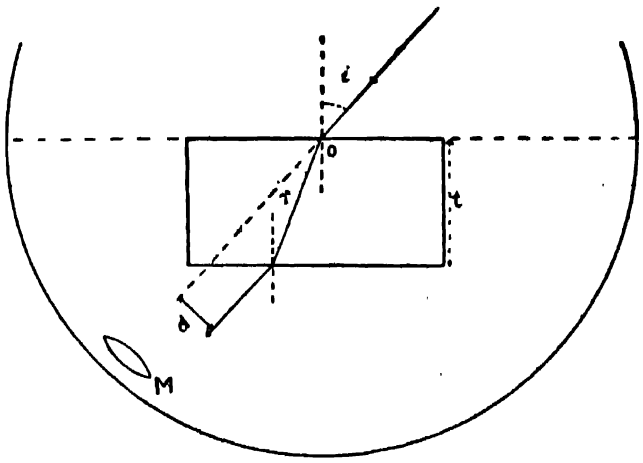

FIGURE 1.

In that paper, measurements of refractive indices of ordinary thin glass and fused quartz plates with respect to sodium light were given. The experimental plate was mounted on a rod fixed along the horizontal axis of rotation of a theodolite whose circular scale and vernier enabled the angles of incidence to be determined. A microscope focussed on a sharp dark line was used to measure its displacement whenever the experimental plate was interposed between the index line and the objective of the microscope so that the angle of incidence was other than zero. It was also stated in that paper that, the method could be further improved both in the direction of higher accuracy of result as well as for the determination of dispersion of the refracting plates. It is the purpose of this paper to describe an experimental arrangement by which refractive indices of thin plates can be determined very conveniently with respect to any wave length of light with an accuracy comparable with that of some of the standard methods known at present.

§ 2. APPARATUS AND ADJUSTMENTS.

The apparatus consists of a spectrometer in which the telescope is replaced by a microscope having scale divisions in the eyepiece.

A Hilger constant deviation spectroscope is used as a monochromator in place of the collimator of the spectrometer. The whole assembled apparatus is shown in plate I, figure 2.

(I) The microscope is focussed on a silk fibre carrying a small plumb placed as nearly as possible on the axis of rotation of the prism table of the spectrometer. A fine line normal to the direction of the light from the monochromator to the microscope is drawn on the prism table passing through the axis of rotation.

(II) The slit of the monochromator is illuminated by sodium light and the drum rotated so that the slit image is in focus exactly on the centre division mark of the eyepiece scale of the microscope.

(III) The experimental plate, if thin, is attached with a little wax to a rectangular metal base piece so that one of its faces, when placed on the prism table contains the axis of rotation. Care is taken to see that the plate is vertical. This face of the plate faces the monochromator. The line drawn on the prism table helps this adjustment.

(IV) Generally, as soon as the refracting plate is put in position on the prism table, the slit image as seen in the microscope will shift from the original position at the centre of the scale. This shift indicates that the light is not falling normally on the plate.

The prism table is then slowly rotated so that the slit image comes back to its former position at the centre of the eyepiece scale. When this is secured the angle of incidence is zero on the plate. The reading of the vernier attached to the prism table is then recorded. The mean of several independent settings is taken as giving the correct position of the material for normal incidence.

Now the prism table is rotated so that the slit image shifts a complete number of the eyepiece scale divisions. The vernier is again read and the difference of the two readings gives the angle of incidence of light on the refracting plate. In actual practice shifts of equal amount on both sides of the initial zero of the eyepiece were produced, involving a change in the angle of rotation by $2i$; from this, i was determined.

The scale divisions of the eyepiece having been calibrated before in cms., the thickness of the experimental plate being known from measurements with a spherometer or some other instrument, all the quantities from which the refractive index of the plate can be determined according to the formula (3) become known, and hence μ is calculated. Similar procedure is followed with respect to any other line of the spectrum which merely a rotation of the monochromator drum brings in the desired position.

§ 3. SOURCES OF LIGHT AND OTHER EXPERIMENTAL DETAILS.

The slit of the monochromator is kept sufficiently wide to give images of sufficient intensity in the focal plane of the observing microscope. The setting can be made on one of the sharp edges of the illuminated slit image, but it was

found a distinct advantage, in practice, if a very fine silk fibre be stretched vertically along the monochromator slit at its middle, and the setting be made with respect to the fine dark shadow of this fibre against the scale division marks of the microscope.

The best sources of light that could be recommended for use are the Geissler tubes or metallic vapour tubes run with an induction coil or a small transformer. Any source in which the luminous vapour flickers, such as an arc, is not suitable for the apparatus, inasmuch as the flickering and the roving of the luminous mass shift the position of the shadow of the silk fibre in the field of view and make accurate setting a matter of some uncertainty. The Geissler tubes on the other hand, have been found in practice to be extremely steady and satisfactory in their behaviour and no shifting of the fibre shadow is at all noticeable.

The spectrometer used in these experiments was supplied by Messrs. Bellingham and Stanley and has a very massive and steady base. The graduated circle a radius of 15 cms., a degree is divided into four divisions in the main scale and the least count is 20″ (seconds). The microscope used had a magnifying power 50.

The apparatus is equally suitable for the determination of refractive indices of liquids. For this purpose, a glass cell is used. The first thing is to determine the refractive indices of the glass walls of the cell with respect to the wave lengths desired to be used for any liquid. This is easily done with the help of the equation (3).

The liquid is now poured in the cell and the combined displacements due to the liquid and glass walls of the cell corresponding to, say, 25 divisions of the eyepiece scale, is produced by making the necessary angle of incidence i, say. For this angle of incidence, using the value of the refractive index for glass for any of the light sources, the displacements due to glass alone is calculated using equation (3) again.

From the total displacement produced, the displacement due to the glass walls of the cell alone is now subtracted. The difference is the displacement due to the liquid alone of thickness corresponding to the distance between the inner faces of the cell walls. This distance is previously determined by careful measurements with a microscope. Knowing i and the displacement due to the liquid alone of a known thickness, the refractive index of the liquid is calculated with the help of equation (3).

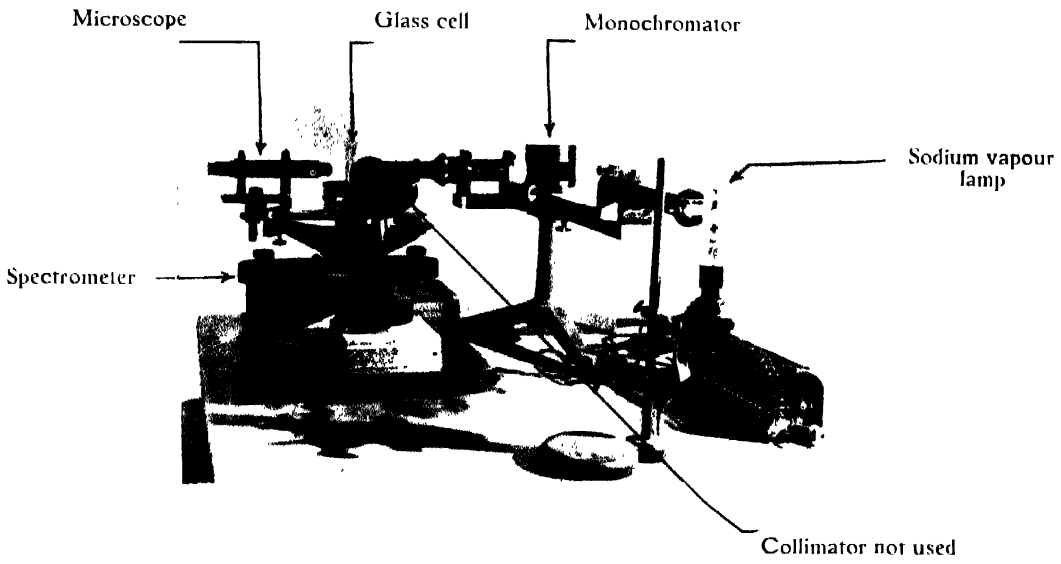
Microscope
Glass cell
Monochromator
Sodium vapour lamp
Spectrometer
Collimator not used

Figure 2.

Measurement of μ for Glass with Sodium Light.

TABLE I.

First sample of glass :—

	Reading of First position.	Reading of Second position.	Difierence .. i	i	Displacement	Ref. Index (μ)
1	191°36'40"	141°50'40"	49°46'00"	24°53'00"	·303 mm.	1·5247
2	191°31'20"	141°42'00"	49°47'20"	24°54'40"	,,	1·5237
3	191°28'20"	141°46'00"	49°42'20"	24°51'10"	,,	1·5257
4	191°35'40"	141°45'20"	49°50'20"	24°55'10"	,	1·5233
5	191°33'00"	141°43'40"	49°49'20"	24°54'40"	,,	1.5237
6	191°28'20°	141°41'00"	49°47'20"	24°53'40"	,,	1.5243
7	191°20'20"	141°36'00"	49°44'20°	24°52'10"	,,	1.5253
8	191°16'40"	141°34'40"	49°42'00"	24°51'00"	,,	1·5261
9	191°17'40"	141°31'40"	49°46'00"	24°53'00"	,,	1.5247
10	191°17'00"	141°33'40"	49°43'20"	24°51'40"	,,	1·5256

Mean value of $\mu = 1·5247$.

Probable error of the result = ±·0002.

Second sample of glass :—

The following values of μ were determined on dismantling and reassembling the apparatus (Na light),

(1) 1·5162. (2) 1·5163 (3) 1·5197 (4) 1·5186 (5) 1·5177

(6) 1·5183. (7) 1·5177 (8) 1·5169 (9) 1·5177 (10) 1·5169

Mean value of $\mu = 1·5176$

Probable error of the result = ±·0002.

Measurement of Dispersion of some Substances.

TABLE II.

Calculated value = A ;

Value reduced to the temperature given in constant book = B ;

Value from the constant book = C.

Substance.	Refractive Indices.			Remarks.
	λ6563	λ5893	λ4861	
Water.	1·3277 at 30°·8	1·3321 at 33°·0C	1·3350 at 30°·8C	A
	1·3278 at 30°·0C	1·3325 at 30°·0C	1·3351 at 30°·0C	B
	1·3302 at 30°·0C	1·3320 at 30°·0C	1·3360 at 30°·0C	C
Toluene.	1·4894 at 29°·8C	1·4946 at 29°·8C	1·5035 at 29°·8C	A
		1·49457 at 30°·0C		B
		1·4918 at 30°·0C		C
Ethyl benzene.	1·4801 at 31°·0C	1·4866 at 31°·0C	1·4972 at 31°·0C	A
		1·4920 at 20°·0C		B
		1·4966 at 20°·0C		C
Benzene.	1·4806 at 31°·8C	1·4936 at 31°·8C	1·5006 at 31°·8C	A
		1·4974 at 25°·0C		B
		1·4979 at 25°·0C		C
Glass.	1·5106	1·5135	1·5198	μ of the material of the cell used.
Quartz (Right handed)	1·5450	1·5499	1·5530	
Didymium glass.	1·5182	1·5222	1·5280	

§ 4. ACCURACY ATTAINABLE WITH THE APPARATUS AND ITS ADVANTAGES.

In the earlier paper (*loc. cit.*) some of the important methods for the accurate determination of refractive indices of thin transparent plates of solids had been

summarised. The results of measurements on glass by successive settings given in table I, show that the probable error of the mean result is ±·0002 and that a dismantling of the whole arrangement and reassemblage do not change the probable error. This means that the apparatus can be relied upon for reproducing results within the same degree of accuracy.

It is interesting to compare the degree of accuracy obtained with this form of refractometer with that which some other well known apparatus possess. The latter is listed in Handbuch der Physik, Band XVIII, 1927, pp. 643, 700, 702, 687, from which it would appear that the uncertainty lies in the fourth decimal place in most cases and this is what is claimed for this apparatus.

A very much higher degree of accuracy has been claimed for the Jamin and the Rayleigh forms of the refractometer, but the strict temperature control necessary to be able in reality to utilise the full power of the instruments with reliability, is a matter of such practical difficulty as to be well nigh impossible of realisation in the majority of cases.

Table II contains results of measurements of refractive indices of a number of liquids and solids with respect to three standard lines, namely the red H_α, green H_β lines of hydrogen, and the yellow line of sodium. These values enable the dispersion of the materials to be easily calculated.

The observed values of refractive indices at the temperature of the experiment have been reduced to the values at temperatures given in the Constant books with the help of appropriate co-efficients when available in the books, for the lines chosen. The best agreements in the case of liquids is to be found for water and benzene for sodium light where the accuracy lies in the fourth decimal place. These were the purest liquids we had. The results with respect to H_α line are not so accurate because of the difficulty of visual observation in that region.

It will thus be seen, that the results obtained with this form of refractometer whose chief merit lies in being inexpensive and capable of being built up of parts easily obtainable in any physical laboratory, are of considerable degree of dependable accuracy.

Further, the instrument to be used requires only a small bit of a plane parallel transparent plate and does not require the substance to be cut in any particular form and thus possesses an advantage of its own.

It is intended to describe the application of this new type of refractometer to the study of the anomalous dispersion of didymium glass, in a subsequent paper.

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REFERENCE.

1 P. S. C. Bulletin No. 8, p. 24, 1933.